ENVIRONMENTAL TEMPERATURES OF FUNGI IN NATURE

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The relation between environmental temperatures and the development of certain fungi—particularly plant parasites—has been the subject of recent study by several investigators.[1] The results of these studies, while highly suggestive, have, of necessity, been somewhat inconclusive because the only material available has consisted of the temperature relations of certain fungi as determined by their behavior in pure culture and of climatic temperatures, *i.e.*, the temperature of the air in shade. The unsatisfactory nature of comparisons made on this basis has been frankly recognized by most of the investigators. Fawcett, for example, remarks in his introduction (p. 184):

> Most organisms (aside from warm-blooded animals) are never exposed, in nature, to maintained temperature for any considerable period of time; their temperature environment is practically always in a state of flux. From this it follows that a knowledge of the relation holding between maintained temperatures and vital processes, no matter how thorough such knowledge may be, can not be expected to be a complete basis for an interpretation of physiological processes going on under natural conditions.

The study of the relation of fungi to their environment is, however, still more complicated by the fact that, as the present notes show, the plant parts living or dead upon which many fungi grow are often, when exposed to the sun, at a temperature much above that of the air. The temperature of these plant parts, moreover, apparently fluctuates under certain conditions much more rapidly than that of the air in the shade.

That the twigs of living peach trees when exposed to the sun often reach a temperature well above that of the air was pointed out over twenty years ago by Whitten.[2] His observations, however, were made chiefly in winter, and the greatest difference he records is 8° C. (air 2.7° C; twig 10.7° C.).

In a series of observations made incidentally during the summer of 1921, much greater differences between the temperature of the air and that of twigs exposed to the sun were frequently observed by the writer. The temperature readings here recorded were all made with mercury thermometers especially made for the work, having cylindrical bulbs 2 mm.

[1] Most of these papers are cited in Fawcett, H. S. The temperature relations of growth in certain parasitic fungi. Univ. Cal. Pub. Agr. Sci. 4: 183–232. 1921.

[2] Whitten, J. C. Das Verhältnis der Farbe zur Tötung von Pfirsichknospen durch Winterfrost. Pp. 1–34. Halle, 1902 (and earlier publications).

in diameter which could readily be thrust into decayed or succulent stems, or between the bark and the wood of firmer stems. These observations may so readily be duplicated that no attempt is made to report them in their entirety, as a few examples will serve as representative of hundreds made on various hosts. They show, in brief, that at night or in the shade the temperature of twigs and small branches approximates that of the air, whereas in the sunlight their temperature is generally above, sometimes as much as 20° C. above that of the air. For example, dead twigs of the cultivated currant (*Ribes* sp.) bearing numerous stromata of the fungus described by Grossenbacher and Duggar[3] as *Botryosphaeria ribis* showed on a clear afternoon the temperatures recorded in table 1.

TABLE 1. *Temperature in Degrees Centigrade of Dead Twigs of the Cultivated Currant Lying on the Ground, North Carver, Mass., May 26, 1921*

Time P.M.	Air in Shade	Bulb of Thermometer Under Bark	Bulb of Thermometer in Center of Twig
1:30	17	33 in sun	27 in sun
2:00	17	36 in sun	29 in sun
2:30	17.2	37 in sun	28.8 in sun
3:00	17.4	36 in sun	27 in sun
3:30	18	18 in shade	18 * in shade
4:00	18.4	18.4 in shade	
4:30	18	17.6 in shade	

* This twig, put back in the sun, rose to 27 in 5 minutes.

This example is by no means unique, since similar results were obtained with currant twigs in other localities, as well as with other dark-colored twigs such as those of black cherry (*Prunus serotina* Ehrh.) and black birch (*Betula lenta* L.). The greatest difference between the temperature of the air and that of a currant twig infected with *Botryosphaeria ribis* yet recorded by the writer was on Overlook Mountain, Woodstock, N. Y., May 13, 1921, when under continuous observation of fifteen minutes (2:00 to 2:15 P.M.) such a currant twig showed a temperature of 37° C. while the temperature of the air in the shade remained at 15.6° C. As might be expected, dark-colored twigs tend to show somewhat higher temperatures in direct sunlight than lighter-colored twigs, as may be demonstrated by exposing small branches of white, yellow, and black birch side by side. That the high temperature of the currant twigs shown in table 1 was due to the heat of the sun is readily shown by the fact that as soon as the shadow of the bank on which they were exposed reached them, their temperature rapidly fell to near that of the air. The same relation is even more clearly shown by the record of temperatures of two blackberry [*Rubus* (probably) *allegheniensis* Porter] canes given in table 2. These canes were near a patch infected with orange leaf rust, so the data given indicate

[3] Grossenbacher, J. G., and Duggar, B. M. A contribution to the life-history, parasitism, and biology of *Botryosphaeria ribis*. N. Y. (Geneva) Agr. Exp. Sta. Tech. Bull. 18. 1911.

to some extent the temperature conditions to which the fungus was exposed on that day.

TABLE 2. *Temperatures in Degrees Centigrade of Blackberry Canes about 1 cm. in Diameter. Thermometer Bulbs placed in the Pith. Livermore, Maine, June 24, 1921. A Day with Drifting Cumulus Clouds*

Time A.M.	Air in Shade	Live Cane	Dead Cane
9:00	24	24 Shade	24 Shade; no sun on plant yet
9:30	24.5	30 Sun	30 Sun
9:45	24	29 Shade	27 Shade
10:00	24	30 Sun	30 Sun
10:50	24	31 Sun	31 Sun
11:00	25	32 Sun	32 Sun
P.M.			
12:30	24.5	31 Shade	31 Shade (for a few minutes)
1:00	25.5	32 Sun	31 Sun
1:30	26	28 This cane shaded by its own leaves	31 Sun
1:35	26	27 This cane shaded by its own leaves	28 Shade
1:40	26	29 This cane shaded by its own leaves	32 Sun
2:00	26	29 This cane shaded by its own leaves	33 Sun
2:30	27	28 This cane shaded by its own leaves	35 Sun
3:00	26	27 This cane shaded by its own leaves	33 Sun
3:30	25	26 This cane shaded by its own leaves	31 Sun
4:00	24.5	25 This cane shaded by its own leaves	28 Sun
4:30	24	24 This cane shaded by its own leaves	27 Sun
6:30	20.5	19.5 Shade	20 Shade
6:45	20	19 Shade	20 Shade
7:00	19	18 Shade	19 Shade

Although the figures published in these notes refer only to twigs and branches, there is abundant evidence that a similar relation holds in the case of other aërial plant parts. Data showing that the temperature of various small fruits in sunlight is usually above that of the air were published in 1918.[4] Individual strawberries (*Fragaria* sp.), for example, were often found to be 10° C. or more above the temperature of the air. These observations agree with those of Müntz[5] (p. 223) on grapes. Müntz found

[4] Stevens, N. E., and Wilcox, R. B. C. Temperatures of small fruits when picked. Plant World **21**: 176–183. 1918.

[5] Müntz, M. A. Recherches expérimentales sur la culture et l'exploitation des vignes. Ann. Sci. Agron. Franc. Étrang. II, 1[1]: 1–272. 1895.

that the temperature of grapes in the morning, before they were exposed to the sun, was only about one degree above that of the air, whereas in the early afternoon red grapes exposed to direct sunlight had, on the day of his observations, a temperature of 37° C. and white grapes a temperature of 34° C. while the temperature of the air in the shade was only 24° C. He found, moreover, that grapes with a dull surface reached a slightly higher temperature when exposed to the sun than those with a bright surface. The importance of these high temperatures in the growth of the numerous fungi found on grapes and strawberries is obvious.

Dufrenoy[6] (p. 16) found that the temperature of leaves of Prunus affected by *Polystigma rubrum* when exposed to sunlight showed a temperature from 8° C. to 11° C. above that of the air. The temperature of the air at the time of the observation was 20° C. while that of the leaves varied with their color from 28.5° C. to 31° C.

The temperature of plant parts underground must fluctuate less rapidly than that of the parts exposed to direct sunlight in the air. Table 3 shows, however, that a fungus like orange leaf rust on Rubus, which is so frequently found on railroad embankments and other sandy, exposed places, may often be subjected, even when underground, to a temperature well above that of the air. The difference in the temperature of the various plants referred to in table 3 was clearly due to the difference in exposure and slope.

TABLE 3. *Temperature in Degrees Centigrade of Soil immediately about the Bases of Dewberry Plants (Rubus villosus Ait.), Affected with Orange Rust, in Typical Location on Side of Gravelly Bank with Eastern Exposure, North Carver, Mass., May 20, 1921*

Time A.M.	Air in Shade	Plant 1	Plant 2	Plant 3	Plant 4
8:00	14	17	18	17.5	18
8:30	15	18.5	30	19	20
9:00	17	20	21	20	21
P.M.					
1:00	23	22	24	25	28
3:00	23	22	22	24	26

Similarly, the weather and soil conditions recorded by Shantz and Piemeisel[7] in connection with their studies of the growth and fructification of *Agaricus tabularis* Peck and *Calvatia cyathiformis* Bosc. at Akron, Colorado, show that the mean temperature of the soil, in which the mycelia of these fairy-ring fungi were growing, was usually different from the

[6] Dufrenoy, M. J. Les conditions écologique du développement des champignons parasites. Bull. Soc. Mycol. France **34**: 8–26. 1918.

[7] Shantz, H. L., and Piemeisel, R. L. Fungus fairy rings in eastern Colorado and their effect on vegetation. Jour. Agr. Res. **11**: 191–245. 1917.

mean temperature of the air. In some cases the difference amounted to as much as 13 or 14 degrees F. (pp. 210, 211).

That the fluctuations in the temperature of twigs exposed to varying conditions of sunlight and shade may be rapid and of considerable extent is evident from parts of tables 1 and 2. The figures there given, however, by no means represent extreme conditions. The most extreme fluctuations yet observed have been those of small dead twigs lying on the ground in full sunlight on days when the sun in an otherwise clear sky is from time to time obscured by drifting clouds. Naturally, when the clouds are not too large, are drifting at a considerable rate of speed, and are separated by fairly wide, clear spaces, the fluctuations in temperature are most rapid and have the longest range. Under such conditions the temperatures given in table 4 were recorded. Even more rapid fluctuations in temperature might be expected on very small twigs, and in measuring the surface temperatures of leaves Mrs. Shreve[8] has noted temperature changes of from one to three degrees C. within from 20 to 60 seconds. With a moderately strong wind blowing, the change amounted to five degrees in 30 seconds.

TABLE 4. *Temperatures in Degrees Centigrade of Birch Twigs on Overlook Mountain, Woodstock, N. Y., May 13, 1921, during a Period of Alternating Sunlight and Shade due to Drifting Clouds*

9:15 to 9:30 A.M.	9:40 to 10:00 A.M.	
Air temperature in the shade during this time varied from 10.5° C. to 13° C.	Air temperature in the shade during this time varied from 10° C. to 12° C.	
Black Birch (*Betula lenta* L.)	Yellow Birch (*Betula lutea* Michx.), Very Thin Bark	White Birch (*Betula alba* L.), Thicker Bark
22 Shade	36 Sun	24 Sun
30 Shade	27 Shade	17 Shade
19 Shade	33 Sun	20 Sun
27 Sun	29 Partial shade	18 Partial shade
17 Shade	35 Sun	23 Sun
30 Sun		

That the conditions under which the data recorded in table 4 were taken are extremely favorable for rapid fluctuation in temperature is shown by numerous unpublished observations made by Dr. H. L. Shantz on solar radiation at Akron, Colorado. Briefly summarized, his observations show, as indicated by figure 1, that the amount of heat received by a given area in intervals of sunlight between cumulus clouds is greater in calories than the same area would receive if there were no clouds in the sky. The explanation of this condition offered by Dr. Shantz is that the amount of heat received in the clear intervals between clouds is augmented by reflection from the surfaces of the clouds themselves.

[8] Shreve, Edith B. Apparatus for determining the temperature of leaves. Yearbook Carnegie Inst. Wash. **17**: 80–81. 1918.

What significance these rapid fluctuations in temperature may have on the physiology of the fungi growing on or in dead twigs, the writer does not attempt to say, but they must have some bearing on the rate of growth

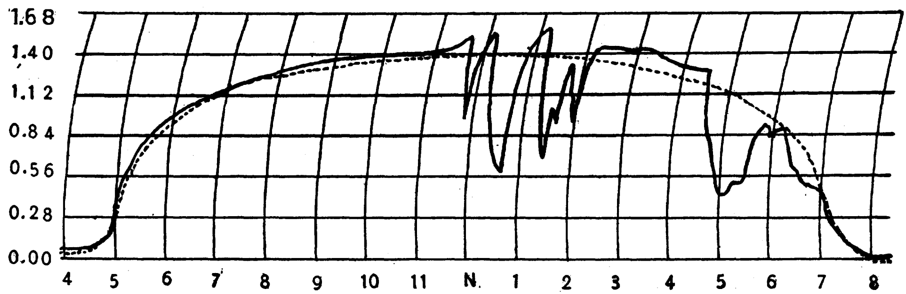

FIG. 1. Total radiation, in gram calories per minute per square centimeter of surface, at Akron, Colorado. Dotted line, July 9, 1914, a clear sky. Solid line, July 11, 1914, a day with drifting clouds.

and fructification of these organisms. It is evident also that the temperature environment of those fungi which grow on leaves and on twigs of deciduous trees must differ widely from that usually supplied them when grown in pure culture in heated laboratories.

SUMMARY

The data presented in the present paper indicate that many plant parts affected by fungi often show, when exposed to the sun, a temperature markedly above that of the air.

They also indicate that the fungi are sometimes subjected to fluctuations of temperature more rapid and extreme than the fluctuations in the temperature of the air in the shade.

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